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THE QUATERNARY GEOLOGY OF THE DUTCH PART OF THE NORTH SEA, NORTH OF THE FRISIAN ISLES

E. OELE[1])

SUMMARY

A geological map of the Dutch part of the North Sea, north of 53°20′ lat. is presented. Fluvioglacial clays of the Elsterian glaciation are presumed to underlie the younger deposits. During the Saalian glaciation the clay was partly eroded by glaciers, which led to the formation of the central deep southeast of the Dogger Bank, the bank itself being an erosion rest. At the same time boulder clay of Scandinavian origin was deposited.

Deposits of the Holsteinian and Eemian interglacials have not been found. Owing to the rapid rise of the sea level supply and sedimentation could not keep up with it.

During the Early- and Late-Weichselian fluvial clays were deposited, while coversands were laid down during Weichselian Pleniglacial times. The surface of the fluvioglacial clay in the central deep remained uncovered owing to strong winds.

The Holocene sequence starts with a basal peat bed, on top of which fresh-water clay settled. The transgreding sea led to the formation first of brackish to marine clayey, later of sandy deposits. (Elbow deposits).

During the Atlantic and Subboreal no sediments were deposited. In the present Subatlantic a reworking and deposition of the material present led to the formation of the young seasand bed.

[1]) Rijks Geologische Dienst Haarlem.

1. INTRODUCTION

General

Examinations of the bottom and subbottom sediments of the North Sea, as far as the Dutch part of the continental shelf is concerned, has been undertaken by the Netherlands State Geological Survey as a continuation of the geological mapping of the Netherlands. Close co-operation with the North Sea Department of the Dutch Ministry of Public Works (Rijkswaterstaat) enabled the Geological Survey to collect sampless on various occasions.

Thus a nautical survey, carried out by the North Sea Department of Rijkswaterstaat in April 1968, made it possible for the author to collect over 90 samples in the northern part of the Dutch continental shelf. The investigated area together with the sampling locations are shown in Figure 1.

Several authors have already been interested in the geology of the North Sea. Only few of them, however, got the opportunity to collect samples systematically. Van Veen (1936) collected data especially in the southern part of the North Sea. Baak (1936) made a study of the petrology of the bottom sediments to trace their source area. Berthois (1957) was interested in the North Sea sediments, Jarke (1956), continuing the work of

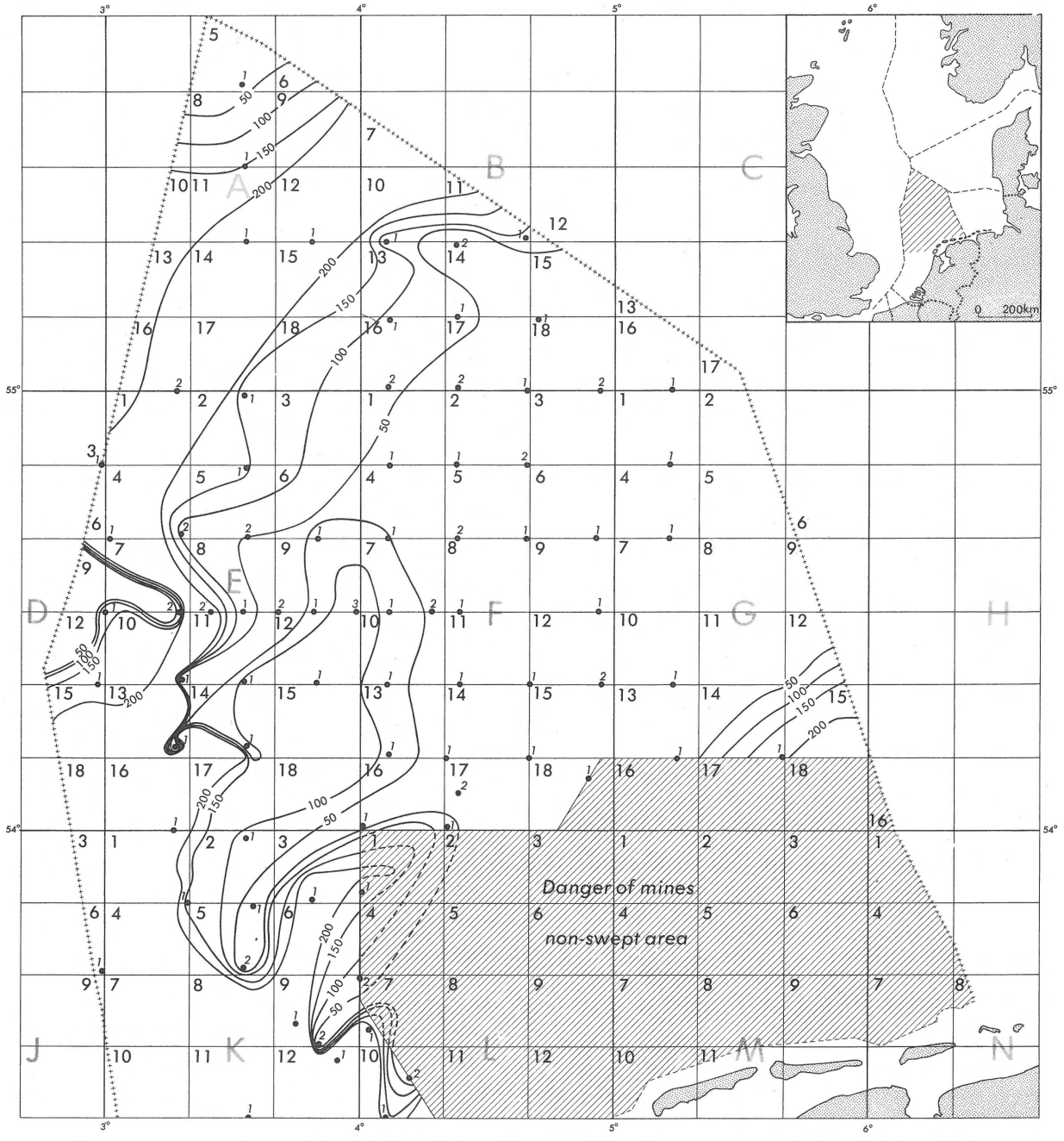


Fig. 1
Map showing investigated area with sampling stations and thickness of young seasand cover.

Pratje, composed a map showing the types of bottom sediments found in the North Sea. V ö l p e l (1959) and S t r i d e (1965) investigated the transport paths of the bottom sediment. H o u b o l t (1968) carried out a survey to collect data on the sedimentology of the ridges occurring in the southern North Sea. V e e n s t r a (1965) sampled a part of the Dogger Bank.

Both the improvements in the sampling equipment brought about in recent years and especially the growing interest in the geology of the North Sea have been favourable enough to promote a regular geological mapping. Following the investigation dealt with in the present paper the whole Dutch part of the shelf is being sampled, again in co-operation with the North Sea Department of Rijkswaterstaat.

Stratigraphy

The stratigraphy of the area has been disclosed by the examination of the pollen and spores on the one hand, of diatoms and ostracods on the other. It is beyond discussion that only when the stratigraphic position of the various deposits is known, a map can be contructed. For this reason the pollen-analysis and its interpretation by Dr. Zagwijn has been of fundamental value. The results were laid down in an internal report. A valuable contribution was obtained from the analysis of the diatoms, especially where they supplemented the botanic data by revealing a depositional environment. These results too have been recorded in internal reports.

Bathymetry

In 1968 the Hydrographer of the Royal Netherlands Navy published a nautical chart of the Dutch part of the continental shelf. The depth soundings on this chart are reduced to mean low water spring. Owing to differences of tidal ranges at different stations, normally a plane constructed through points of equal depths is not a horizontal one. In this respect a reference to the mean sea level plane as suggested earlier by S t o c k s (1956) would be better, because it would enable one to read the bottom morphology from the chart. Basing it on a level approximating the mean sea level, Stocks constructed a bathymetric map of the North Sea, the equidistance being 10 metres.

The area investigated by the present author appears to be rather flat on this map, while the figures on the Dutch nautical map suggest a more shaded topography. Because tidal movements in the investigated area are very small, the vertical tidal range being about 0.5 metre, the inaccuracy will be negligible when use is made of the depth figures on the Dutch nautical map. Therefore it is preferable to draw the isobaths on the basis of these figures.

In contrast with Stocks' opinion the area deeper than 50 metres is thought to form a depression in the centre of the area, extending to the NE beyond the border of the Dutch part of the shelf.

2. SAMPLING TECHNIQUES

The Geological Survey started work at sea with the use of a gravity corer as developed and described by V a n d e n B u s s c h e & H o u b o l t (1964). In the sediments near the Dutch coast, however, its penetration appeared to be on the whole less than 40 cm, except in very recent loose sands, where a penetration of over 1.00 metre is possible. Normally the base of the young seasand deposits (recent to subrecent) will not be found within such small depth-ranges. Therefore the Geological Survey gratefully accepted the offer to copy a vibracorer also developed by Ir. Van den Bussche for the B.I.P.M.

After some slight modifications to its prototype, cores with a length of 3.10 m were taken in sands with the vibracorer. Yet great difficulties are still being encountered in dealing with tough clays or peat. These sediments stick strongly to the side of the sampling tube, causing the material to move up the tube only over a short distance. Consequently peat or clay samples normally do not exceed 1 metre or even less in length.

The samples are pressed out of the sampling tube, by means of compressed air after which they are cut in two.

3. THE QUATERNARY GEOLOGY OF THE NORTHERN NETHERLANDS

The geological history of the Netherlands during the Quaternary has been dealt with in various papers. An extensive synopsis has been published recently by D e J o n g (1967) while P o n s et al (1963) gave a reconstruction of the geological history of the coastal areas in Holocene times. Still, a brief review of the

Pleistocene and Holocene history of the Northern part of the Netherlands adjacent to our area of investigation, would not be out of place in this paper.

Pleistocene

The sedimentation of marine Icenian deposits in the beginning of the Pleistocene was followed by a series of fluviatile sediments (Formations of Harderwijk and Enschede). The material of these formations, which were both completed before the Cromerian started, was derived from a source area lying northeast and east of the site of deposition respectively. This can be concluded from the heavy-mineral assemblages of the sands (Z o n n e v e l d, 1958).

In several parts of the northwestern Netherlands typical Rhine deposits (Formations of Sterksel and Urk) are found overlying the formations mentioned above. Deposition of these coarse sands started at the beginning of the Cromerian Interglacial, continued throughout the Elsterian Glacial (at least in the central Netherlands) and lasted until the end of the Holsteinian Interglacial. During the Elsterian Glacial the "pottery clay" found in the provinces of Friesland and Groningen is supposed to have settled in ice-dammed lakes (Z o n n e v e l d, 1958).

Besides these fluvial deposits a marine formation was built up during the Holsteinian Interglacial as a result of sea-level rise. This formation, consisting of coarse sands, is found in the Wadden area.

Deposition of the mainly fluviatile sediments completed, the sedimentary environment was entirely glacially controlled during the following Saalian Glacial. In front of the land ice predominantly fine sediments were deposited (Formation of Eindhoven). These sediments are considered to represent the fine fractions of the Formations of Urk and Enschede, blown out by wind and finally deposited by wind or meltwater streams (T e r W e e, 1966). Subsequent glaciation resulted in the deposition of tills and meltwater deposits.

After the Saalian Glacial the sea transgreded again and built the deposits of the marine Eemian Formation, which consists of coarse sands and clays.

During the last glacial, the Weichselian, the main sediments deposited are the coversands. Under periglacial conditions sand was blown over the barren land. The deposits are considered to be niveo-eolian sediments.

Holocene

The milder climate as well as the continued rise of the sea level, which in its turn caused a rise of the ground-water table, initially led to a restoration of the vegetation. Ultimately the ground-water table rose to such levels, that peat growth started. On the other hand the continuation of the sea-level rise, resulted in marine transgressions and the deposition of marine sediments. Therefore the peat is often overlain by a clay bed formed in a brackish-water or marine environment.

Peat growth and deposition of clay took place during Preboreal and Boreal times. During the subsequent Atlanticum the sedimentary environment changed into a tidal flat environment, resulting in the deposition of mainly fine sands and clays.

From various places it is known that in the same period the transgressing sea cut deep gullies in the already deposited sediment, which were filled again probably during Late-Atlantic times.

A retardation in sea-level rise during the Subboreal led again to the formation of a (second) peat layer. This peat is overlain by a series of tidal-flat deposits, built during the Subatlantic behind a series of coastal barriers.

4. RESULTS OF THE INVESTIGATION

Although the vibracorer did not reach deeper than 3 metres or even less, it has been possible to penetrate deposits, older than the toplayer consisting of recent to subrecent "young seasand". Examinations of the cores revealed that several of the Quaternary lithostratigraphic units found in the Netherlands can be recognized to the North as well. The following units have been distinguished:

Young seasand deposits

As stated before the toplayer of the seabed is rather uniform over the whole area and consists of fine sand. The sand is subrounded and rather well sorted with a diameter of about 150 microns. The sands closely resemble the Pleistocene coversands from which they are distinguishable only by the presence of shell débris and the lack of humic remains. Only near the Isle of Texel is the sand somewhat coarser and, occasionally, contains gravel.

The gravel components indicate that they are remnants of glacial deposits, from wich the finer particles have been washed-out.

Among the shell remains found in this layer are parts of *Cardium edule, Donax vittatus, Cyprina islandica, Spisula subtruncate, Ensis ensis.*

The presence of the pollen *Fagus* and *Carpinus* reveals a Late-Subatlantic age of the young seasand deposits.

In some places the seabed consist of soft clay. This young clay (see also Zagwijn & Veenstra, 1966) probably is locally reworked older clay which directly underlies the soft clay.

Early-Holocene brackish-marine deposits (Elbow deposits)

In several localities the yellowish brown young seasand appears to overlie grey sands, which differ in various respects from the above mentioned sand. Grain sizes are almost the same, but the amount of particles < 16 microns is much higher. Clay laminae are sometimes intercalated, while also small lumps of clay and peat can be observed. Shell fragments are rare, subrecent forms being absent. On the other hand fragments of amongst others *Hydrobia ulvae* indicate that the sands were deposited in shallow brackish-marine environment.

The sandy deposits overlie clay beds, which are pollen-analytically dated as Boreal. The clay is grey and mostly fat and tough, sandy laminae sometimes being intercalated. Shell remains are present (a.o. *Cardium edule,* the *breed of Carium edule, Mytilus edule).* Ostracods found in the clay indicate a shallow, fully marine environment or a fully marine tidal flat. The latter environment is more in accordance with the structures present (Fig. 2).

The deposits are assumed to be the lithological equivalent of the Velsen Clay and old tidal-flat deposits of western Holland. As stated before in western Holland too old-holocene tidal-flat deposits are found on top of the Lower Peat. They are called Calais deposits. Deposition of the tidal-flat sediments and the Lower Peat is closely related to the rise of the sea level. As a result they are lithostratigraphic and not chronostratigraphic units. So the Boreal tidal-flat deposits, found in the investigated area are assumed to represent an older part of the lithostratigraphic unit, which in Holland comprises the Calais deposits. Unfortunately the term "Calais" is restricted to the marine deposits that are Atlantic or Early-Subboreal in age (Hageman, 1963). Hence for these older deposits, although belonging to the same lithostratigraphic unit, a new term must be introduced. The present author proposes the term Elbow deposits to be used for non-terrestrial sediments present in Holland and adjoining regions ranging in age from Preboreal to Boreal.

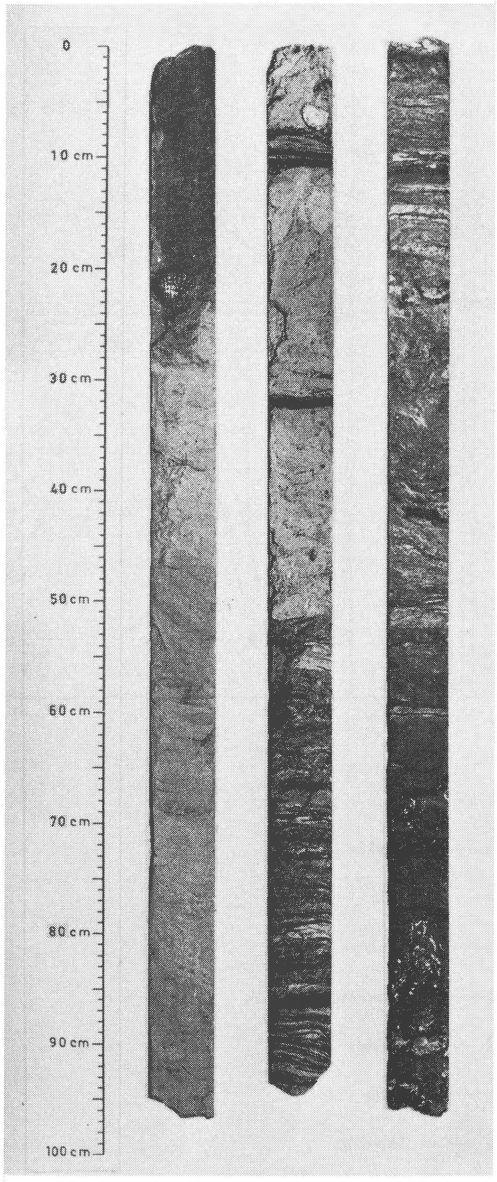


Fig. 2
Lacquer peer of core B 18-1, visualizing transition of Preboreal marine Elbow clay to Elbow sands and young seasand.

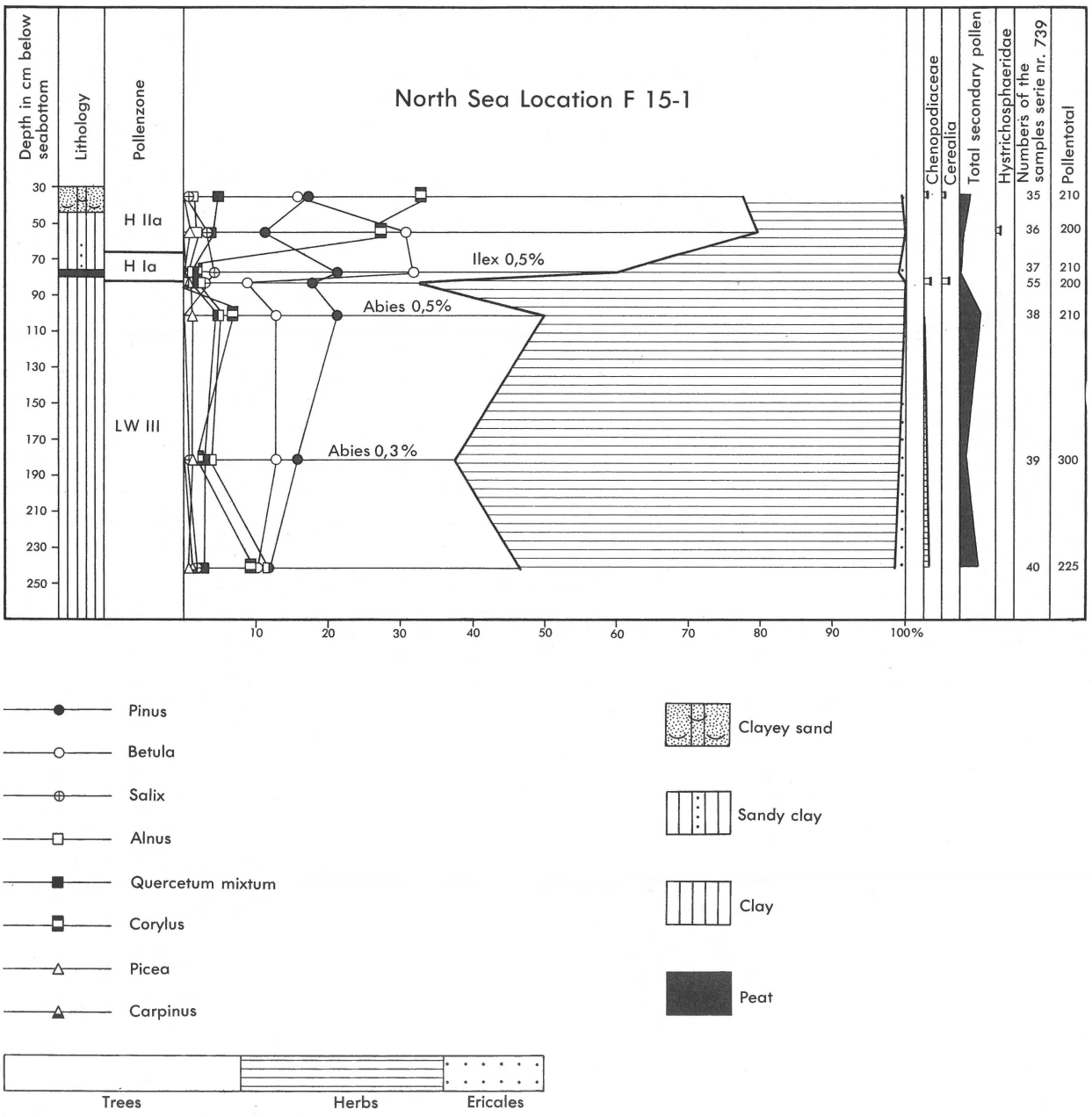


Fig. 3
Pollen-diagram showing the transition of Late-Weichselian deposits to Preboreal peat and Boreal clay (after Zagwijn, 1969).

Preboreal peat.

The Lower Peat, constituting the base of the Holocene sequence in western Holland, can be traced far out into the sea. Peat found in location F 15-1 was pollen-analytically dated as a Preboreal deposit. The peat is intercalated between clay beds. The pollen assemblage of the sequence clearly marks the transition from the Late-Dryas stadial via the Preboreal peat to the Boreal clay. The pollen diagram is represented in Fig. 3.

The fresh-water clay on top of the Lower Peat is regarded as belonging to the Lower-Peat Formation. Data on the distribution of the clay are too inconclusive to allow a special subdivision on the map.

Coversands.

Lower Peat formations often occur on series of sands, the so called coversands. These are well-sorted sands with occasional thin loamy laminae. The diameter of the grain-size distribution is about 150 microns. Traces of plant remains are present but rare.

The coversands of core C 16-1 were dated by means of pollen-analysis. The lower part of the coversand is to be placed in the Early-Weichselian (Brandenburg or Frankfurt phase of the Würm) the upper part representing the Pleniglacial of the Weichselian (Pomerian phase of the Würm).

Other Weichselian deposits.

The clays of two other locations yield a Weichselian age as well. A fresh-water clay, present in core F 15-1 appeared to have settled during the Late-Dryas.

The clay of core F 12-2 on the other hand is for its pollencontent thought to be Early-Weichselian in age.

Glaciogenic deposits.

In two locations a real till deposit has been found. Earlier workers (P r a t j e, 1951; B e r t h o i s, 1957; V e e n s t r a, 1965) recorded boulder clays from positions in a more westerly direction. The boulder clay collected by Veenstra was deposited by glaciers, coming from the British Isles (Z a g w i j n & V e e n s t r a, 1966). British and Scandinavian clays can be distinguished, because the British clays are rich in Carboniferons and Jurassic spores, the Scandinavian containing pollen ranging from the Cretaceous to the Middle Pleistocene. This is in accordance with the assumption that the gravel on top of the Dogger Bank contains only a small amount of gravel. Fragments of flint, granite and sandstone are present. Their numbers are too small to draw any conclusions as to the source area. The pollen clearly suggest a Scandinavian origin. The clay shows weathering phenomena and contains remains resembling remnants of roots. These features are being investigated more closely by the Netherlands Soil Survey Institute.

In various other borings a clay occurs which, according to its pollen content, must have settled during a glaciation. The clay is very tough and laminated. It strongly resembles fluvioglacial clay present in Holland. Therefore it is regarded as such. Moreover, the pollen make it clear that the clay is Scandinavian and not British originally. It has the same reddish colour as the boulder clay.

5. INTERPRETATION OF THE RESULTS (Plates I and II).

Pleistocene deposits

As to the glaciogenic sediments, the samples do not present evidence concerning the stratigraphic position of the boulder clay with respect to the fluvioglacial clay. The depths at which the two kinds of deposits occur suggest that the boulder clay overlies the fluvioglacial clay and is the younger one. Since fluvioglaciaal clay has been found in a great many borings, whereas locations of boulder clay are rare, the latter apparently does not form a continuous bed on top of the fluvioglacial clay.

As is shown in the N-S striking section (Plate II), the surface of the fluvioglacial clay clearly slopes gently from the flanks of the Dogger Bank in the North into the depression SE of it. This being the case, it is suggested that the surface then rises again to be connected with the clay surface found in the borings G 10-1 and G 14-1 still further to the SE. Thus the surface of the clay builds a NE-SW striking trough. From the data collected it follows that the trough extends to the NE beyond the Dutch part of the shelf. In the SW the data are inconclusive.

As stated before some deposits are dated Early-Weichselian. From the assumed dip of its surface it would follow that the fluvioglacial clay underlies these almost outcropping Weichselian sediments as well. Consequently, the clay must have been deposited prior to the Weichselian glaciation.

The shape of the clay surface might be due to erosion features, but its smooth curvature and the sticky nature of the clay does not make fluviatile erosion likely. Glacial erosion would be a more likely cause of the present shape. On top of the partly eroded clay the glacier afterwards deposited the boulder clay.

The foregoing therefore leads to the conclusion that the fluvioglacial clay settled during a glaciation prior to the Weichselian glaciation, i.e. during the Saalian or the Elsterian. This sedimentation was followed by a glacial erosion and subsequent depostion of boulder clay. Unlike the age of the fluvioglacial clay, the age of the boulder clay cannot be derived from its position with respect to the dated Early-Weichselian deposits.

The isolated occurrence of the latter makes it impossible to establish their interrelationship. In fact

the Early-Weichselian deposits may have been intercalated between the fluvioglacial clay and the boulder clay. Theoretically, therefore, the flucioglacial clay may have been eroded during the Saalian, after which interglacial sediments – to which in a sense the Early-Weichselian deposits might be reckoned as well – were deposited, subsequently overlain by boulder clay of Weichselian age. Yet, it is supposed that the boulder clay is of Saalian age, while the fluvioglacial clay is Elsterian for the following reasons:

a. If the gently rising surface of the clay is extended from the earlier mentioned borings G 10-1 and B 14-4 in the direction of the Frisian Islands, it appears to coincide exactly with the surface of the fluvioglacial clay as it is present in borings near the isle of Ameland at a depth of about 30 metres below O.D.
b. In the North of Holland the same sequence of boulder clay on top of fluvioglacial clay is found.
c. Since in the North of Holland all fluvioglacial clay deposits are Elsterian, and no Saalian sediments of this kind are known, it is likely that in the adjoining area too these deposits are Elsterian.
d. The ice of the Saalian glaciation covered a great part of the North Sea basin, reaching as far south as Amsterdam in the present coastal areas and as far as Dusseldorf farther inland, while the extension of the Weichselian glacier is still unknown. Therefore, if only one boulder clay deposit is found, it is expected to be part of the Saalian boulder clay, occurring over a vast area rather than to form an isolated occurrence of Weichselian clay without any trace of its Saalian counterpart.

If this has been the course of events, then, apart from the Early-Weichselian deposits, sediments of the two interglaciale involved are lacking. The question arises in what way the Weichselian glaciation influenced the area.

As has been said before an extension of the fluvioglacial clay to the SW of the investigated area is uncertain. Sediments of Holsteinian age might be present. Their presence, however, in the central and NE parts of the area can be excluded on account of the erosive activity of the Saalian glaciers.

Although it is known that in the Early-Eemian, when the sea level rose eustatically, sands were deposited in western Holland, such sedimentation need not have taken place further to the North. First of all the rivers Rhine and Meuse have been flowing westward since the Saalian. Secondly, according to Zagwijn (personal communication), the rise of the sea level has been rapid, so that sedimentation could probably not keep up with it. In the investigated area the tidal currents will soon have been the only means of sediment transport. As they are today these currents may have been too weak to cause any transport of sediment at all.

It is therefore doubtful whether sedimentation during the Eemian was of any importance. Moreover, part of the material deposited will have been eroded at the end of the Eemian and the beginning of the Weichselian, when the sea level lowered as a result of renewed glaciation.

The investigated area is supposed to belong during the Weichselian to the periglacial zone. Deposition of the aeolian coversands was the main form of sedimentation, the subaquatic deposits playing only a minor role. Coversand deposits are found on the Dogger Bank and in the southeastern part of the central depression, from where its thickness gradually increases further to the SE. Again the distribution of these sands in the southwestern part is unknown.

However, it is clear that the sands are absent in a zone parallel to the axis of the central depression, just to the NW of it. This zone is thought to reflect the area which was laid barren or kept barren by the winds that formed the coversand ridges elsewhere.

The interpretation of the data, as given above, implies that the surface of the fluvioglacial clay reflects to a certain extent the present topography. The surface just mentioned is thought to have been moulded by the Saalian glaciers, making the latter basically responsible for the bottom topography too. It means that a.o. the Dogger Bank constitutes a high ground, because it was not or only slightly affected by the Saalian glacial erosion. Although I agree with Stride (1959) that boulder clay covered by young Pleistocene sediments is certain to occur on the Dogger Bank, this bank is to be considered as an erosion rest rather than having a morainic frame work. During the Weichselian the bank was covered by aeolian sands, and in the postglacial period valleys, now known as gullies were formed by meltwater as suggested by Valentin (1955). Unlike Veenstra (1965), the present author ascribes the strong relief of the Dogger Bank not to the great influence of the Weichselian glaciation, but to the fact, that during the Eemian interglacial as well as during the Holocene the sea level rose very rapidly. Consequent-

ly the Dogger Bank soon came to lie at such a depth, that it was free from wave attack.

Holocene deposits

As in western Holland the beginning of the Holocene is marked by the occurrence of the Lower Peat bed. As far as our sampling is concerned peat has only been found in the southeastern part of the investigated area. However, moorlogs have been recorded from the Dogger Bank by earlier workers (a.o. Vermeer-Louman, 1934). It means that peat must also be present near or at the surface around the Dogger Bank. However the present study suggests that it may be absent on the southeastern flank of the Dogger Bank. More data are required to explain its absence, which might be due to erosion or non-deposition.

The peat collected by the author occurs at a depth of approximately 47 metres below O.D. Since it is dated as Early-Preboreal the depth roughly fits the curve of Jelgersma (1961), representing the Early-Holocene sea-level change in the North Sea extrapolated to the Early-Preboreal.

In boring F 15-1 the Lower Peat is found to be intercalated between non-marine clays. In western Holland normally on top of the Lower Peat a brackish-water clay (Velsen Clay) is found, which leads to the conclusion that the transgression of the sea stopped peat growth.

The same succession as found in boring F 15-1 was observed in a boring west of Hook of Holland. The diatoms prove that there too a fresh-water clay overlies the peat. As suggested by Jelgersma (personal communication) the rising sea level may have driven the waters of the rivers into their estuaries. In support of this view is the assemblage of diatoms found in the clay of boring F 15-1. According to Du Saar the assemblage is the same as that present in clays of the Biesbos area, i.e. a delta in the upper part of an estuary, influenced by the tides, but owing to its distance from the sea only very slightly brackish. It is possible that the German rivers Weser and Elbe had their estuaries in the area of investigation, which may also account for the fact that somewhat earlier the site was favourable for peat growth. In other locations the same clay has been observed, which, for its age, (Boreal) is thought to be the equivalent of the former.

The presence of Boreal clays, having settled in a brackish to marine environment demonstrated that events were similar to those in later times in Holland and the adjoining coastal regions. The depositional environment changed into a tidal flat, where apparently after the deposition of the clay sedimentation had a more sandy character.

It is remarkable, that the occurrence of the clay is restricted to the centre of the investigated area, which is also the deepest part. It is also the area, where the surface of the fluvioglacial clay was laid barren during the Weichselian. So, when the sea invaded the region, where fluviatile transport played a minor role, at first relatively small amounts of sand were avaible to be removed and transported by the waves and currents of the invading sea. In later stages the extensive cover of aeolian Weichselian sands supplied the material to build the Elbow sands.

The Elbow sands constitute a belt, which to the SE is bounded by an area with coversands nearly at the surface, while to the NW on the flank of the Dogger Bank its occurrence is hidden by a thick layer of young seasand.

On top of the Dogger Bank Stride (1959) collected material which he describes as an Old-Holocene tidal-flat deposit. Because of the depth at which the sands were sampled, their age must, however, be younger (end of the Boreal to the beginning of the Atlanticum) than the Elbow sands.

The question arises whether the tidal-flat sediments were deposited behind barriers or not. Most of the deposits are found at depths of 45 metres or more. Assuming that at the time of deposition the sea level stood at approximately the same depth, only a relatively narrow opening existed between the open sea and the tidal flat.

The deposits mentioned before are all covered by young seasand. On account of their resemblance to the coversands and their specific heavy-mineral assemblage (Baak, 1936) the sands in the investigated area must be considered not to have been supplied by tidal currents from the southern bight of the North Sea. Stride (1965) assumes a transport along the Dutch coast and the Frisian isles in a northern direction. This is not likely, however, because of the differences noted between the sands in the southern and the northern parts of the Dutch coast the boundary lying near Bergen, (see also Eisma, 1968). The author agrees with Völpel (1959 and Houbolt (1968) that in the North a distinct and separate sedimentary system exists.

The thickness of the young seasand layer varies greatly, as is shown in Fig. 1. In the SW the thickness is over 2 metres, that is in a zone along the Dogger Bank. In several places on the Dogger Bank as well as SE of the central deep the Weichselian coversands crop out. Of course the question arises, whether the distribution of the recent bottom sediments is more or less stabel or is still changing. According to V ö l p e l (1959) definite paths of transport exist. They are supposed to coincide with the course of the tidal currents and be especially important when they occur at depths of 20-30 metres. His conclusions are based on small differences in grain-size distribution. Given the small range of the grain size of the source material, marine transport can have affected the grain-size distribution only slightly. Therefore, grain-size distribution may not be respresentative with respect to the transport.

As V e e n s t r a (1965) has already said sedimentation has not been continuous since the marine transgression. It therefore hardly seems to make sense to calculate sedimentation rates. The matter will be dealt with more extensively in a forthcoming paper on the sedimentological aspects of the area.

6. CONCLUSIONS

The interpretation of the data collected during the present survey led to the assumption of the following series of events.

During the Elsterian glaciation fluvioglacial clay was deposited over a vast area and now occurs as a basal bed all over the investigated area. It is also thought to underlie the Dogger Bank at a relatively small depth below the surface of the bank. The upper part of the clay was partly eroded due to scour by Saalian glaciers. In fact the present bottom topography may be the result of glacial erosion: so the Dogger Bank is regarded as an erosion rest. This does not necessarily exclude the bank having been covered subsequently by the ice.

The boulder clay which was found on top of the fluvioglacial clay in various localities consists of Scandinavian material. Since the glacial deposits on the westerly part of the Dogger Bank are of Scottish origin, the bank respresents the region where the glaciers of both source areas melted together.

During the interglacials, the Holsteinian and the Eemian, no sedimentation of importance took place. In both interglacials the sea level rose so rapidly, that supply of material could not keep up with it. Moreover both interglacials were closed by a period of erosion as a result of a renewed lowering of sea level.

The Weichselian glaciation resulted in the deposition of the aeolian coversands. The sands accumulated against the SE flank of the central deep and the top of the Dogger Bank. In the central deep the surface of the fluvioglacial clay was laid barren by strong winds. In the Early-Weichselian as in the Late-Weichselian small streams led to the deposition of a fresh-water clay.

The Holocene history of Western Holland reflects the events in the Early-Holocene of the investigated area. Peat-growth started as a result of the continuing rise of the ground-water table. Peat was not found on the southeastern flank of the Dogger Bank. The rising watertable caused the land to be drowned and a fresh-water clay settled on top of the peat. Gradually the influence of the transgression increased. Brackish-marine clays in a tidal-flat area were formed. Due to the continued rise of the sea level the coversands on the higher grounds were attacked and supplied material for the sandy marine deposits. Because of their Boreal age these brackish marine deposits do not belong to the Calais deposits and are called Elbow deposits.

Again sea-level rise went on so rapidly, that soon the waves hardly influenced the bottom. This also explains why the appearance of the Dogger Bank topography is still rather fresh. A layer of young seasand (subrecent-recent) covers the older deposits, its thickness varying greatly.

7. ACKNOWLEDGEMENTS

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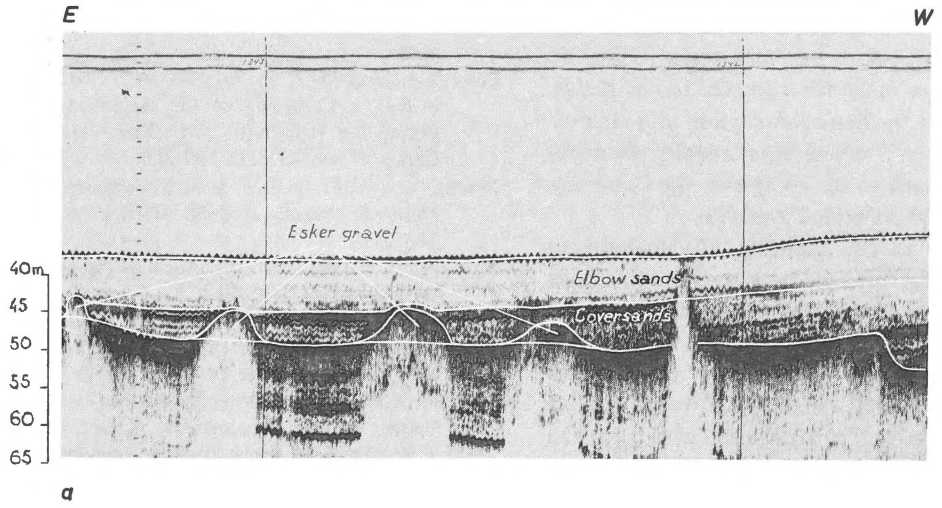
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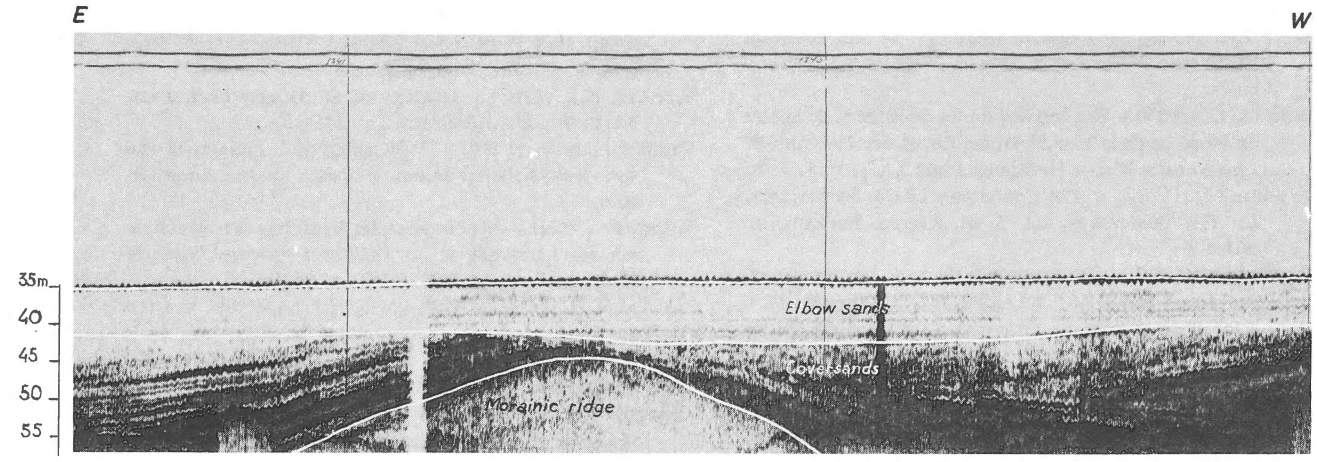
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APPENDIX

Recently, after the foregoing paper had been completed, a survey with a continuous profiler was carried out by the Dutch Coastal Engineering Survey



a



a continued

Fig. 4a
Sonia records from sites near boring E9-2 (A) and F10-1 (B). For explanation see text. Hor. scale appr. 1 : 16000; vert. scale of the part below sea bottom appr. 1 : 1000

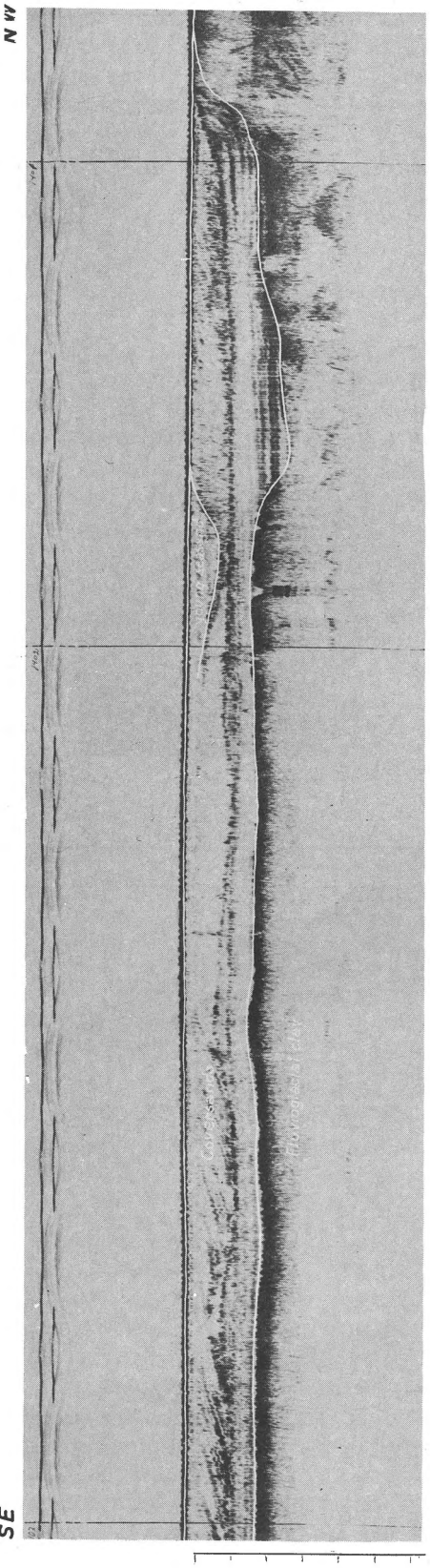


Fig. 4b

Consultants CESCO N.V. the Hague, including the area just described. The records, or sonograms, produced by Cesco's "Sonia" were in several locations checked by means of borings. The sonograms clearly show the units distinguished before.

Two parts of the records are represented in Fig. 4. They are interpreted as follows.

In Fig. 4A a ridge can be seen which is thought to represent part of a moraine ridge, the pushing ice having come from the East (left in the photo). The strongly reflecting layer behind the moraine represents the top of the fluvioglacial clay. The interrupted deposition of clay layers on the record must be ascribed to the fact, that the sound could not penetrate in places, which in its turn is supposed to have been caused by the presence of gravel in the convexities found on the record. The latter are thought to belong to an esker or osar which, owing to its winding course, is crossed several times.

The glacial deposits are overlain by the Weichselian coversands, which show a cross-bedded structure (Fig. 4A, right). Above an erosion plane, cutting the coversands, the marine Elbow sands with thin clay layers are found.

In Fig. 4B the surface of the fluvioglacial clay again is clearly marked. The series of Weichselian coversands overlying the clay is in its lower part horizontally bedded, while in its upper part a cross-bedding is present.

I am much indebted to Cesco for their permission to publish these photographs of the Sonia record, which give such a good idea of the layering below the sea bottom.